Field and Laboratory Investigation of High-Speed Ferry Wake Impacts in New York Harbor

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1. Introduction

The last 10 years have witnessed a tremendous growth in passenger ferry service in the New York metropolitan region, a growth that is mirrored in many other areas of the world as more and more urban shorelines experience revitalization – some would say a transformation. This revitalization has in a very real sense been brought about by success in restoring our urban waterways. Estuaries like the Hudson-Raritan Estuary are once again vital and vibrant habitat, and offer recreational and commercial opportunities to thousands of residents and visitors. Urban waterways also serve as hosts to the US Marine Transportation System (MTS), a system that is responsible not only for passenger ferry transportation, but also for more than 95% of U.S. international trade. The Port of New York and New Jersey, among the largest in the nation, is a critical component of the national and global MTS.

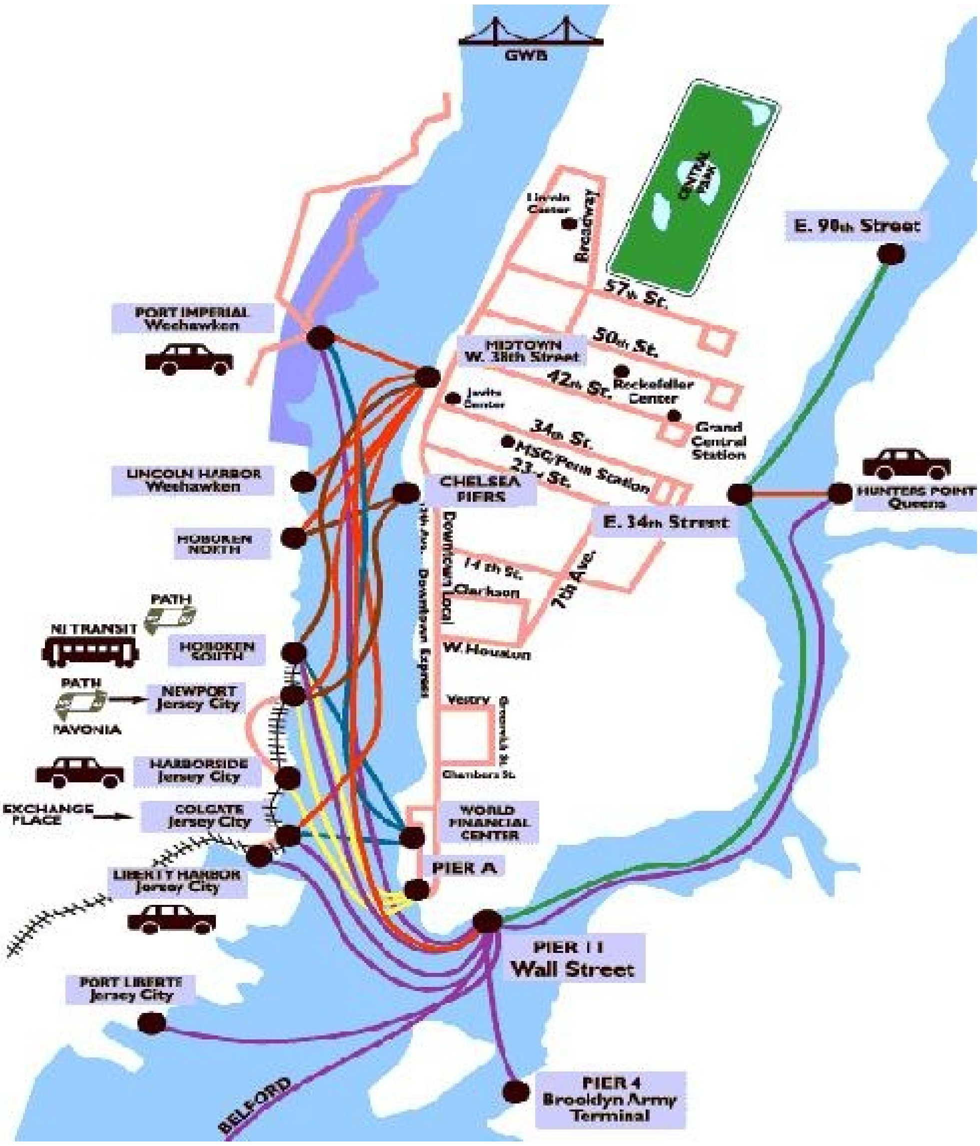

Fig.1: Ferry route map for NY Waterways

The mixed use of the urban estuary – including marine transportation, commercial and recreational fishing, and pleasure boating, among others - creates complex user needs and, unfortunately, conflicts. The recent rapid growth in high-speed ferry service in the Hudson River (see Fig.1 for a route map of the primary ferry service) has created the potential for one such conflict – the need to provide reliable waterborne passenger transportation while at the same time ensuring that wave-sensitive shoreline facilities and activities are not adversely impacted. Of particular concern are:

- Impact to vessels in exposed and partially-protected dock areas and marinas
- Damage to bulkheads and other shoreline structures
- Erosion of natural shorelines and wetlands
- Impacts to sea grass and shellfish beds
- Safety of passing vessels, particularly small craft

In response to this issue, the State of New Jersey requested that Stevens Institute of Technology conduct a comprehensive study of the New York Harbor wake problem with a view toward developing recommendations to enable efficient passenger ferry service while also minimizing any identified adverse impacts associated with ferry wakes. The Stevens study is now complete and has been approved by the Harbor Operations Committee of New York – New Jersey Harbor. We here summarize our findings and recommendations, and also provide the preliminary findings from more recent field measurements in the Harbor.

2. Study description and results

The study of ferry-generated wakes in New York Harbor involves the consideration of various factors: complicated bathymetry, ambient wave field, various types of vessels, their speed, acceleration and course changes. With this in mind, it was decided to study the problem by a combination of qualitative and quantitative field measurements, and laboratory measurements of wake wash from small-scale models.

The study contained several elements, including:

- field observations of wave characteristics in the Hudson River over a multi-week period;
- visual observations of ferry wake generation, ferry routing, docking and departing procedures, etc.;
- scale model studies of ferry wake generation using the Stevens high-speed towing tank and scale models representing a variety of ferry hull forms, including monohulls and catamarans, operating over a wide range of speeds;
- meetings with the full range of stakeholders, including ferry captains, marina owners and operators, commercial vessel captains, the New York Harbor Operations Committee, and Federal, State and local government officials.

2.1. Field Observations, July, 2002

A field study was undertaken in July, 2002. High-resolution pressure gauges were deployed for slightly over eight days beginning the afternoon of July 10th. Two gauges were situated so as to obtain time series pressure records that would provide a description of the wave heights and wave periods found in the Harbor. The Harbor bathymetry is characterized by a deep (~20 m) channel flanked in most areas by a narrow, flat, and shallow (~3 m) shelf. One gauge was placed at a depth of 11 m in the channel, approximately 100 m seaward of the pier head line. The second gauge was placed at a depth of 4 m, inshore of the pier head line. The two gauges were located near the NY Waterways Lincoln Harbor ferry terminal (see Fig.1) and as such near an active fast ferry route.

The 8-day surface elevation time series for the offshore gauge is given in Fig.2. The time series indicates a strong diurnal pattern of relatively calm overnight periods followed by very energetic periods. The highest waves in the day occur during two peak periods. The first peak period of each day begins as a gradual increase starting at approximately 0530 EDT and peaking at approximately 0915 EDT, which corresponds to the morning rush hour. Wave heights then gradually diminish, but only to levels well above the typical overnight values, until approximately 1245 EDT when they again begin to increase as the evening rush hour is approached. After the second and typically highest peak of the day at approximately 1745 EDT, the wave heights gradually diminish until they reach the typical overnight values some time shortly after 2330 EDT. Overnight maximum wave heights range from 4 inches to 6 inches (10 to 15 cm). The morning peak heights are typically between 12 inches and 16 inches (30 to 40 cm). Similar behavior was observed by the inshore gauge, although the inshore gauge typically recorded wave heights between 5% and 10% higher than the offshore gauge, likely because of the effect of shoaling and/or wave reflections from the shoreline.

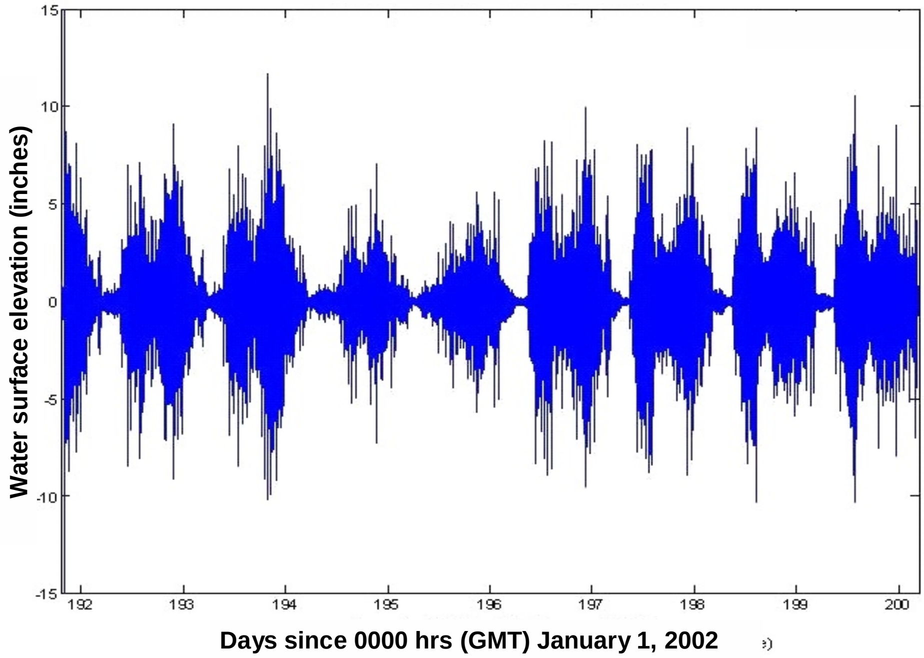

Fig.2: Time history of water surface elevation for 8-day period

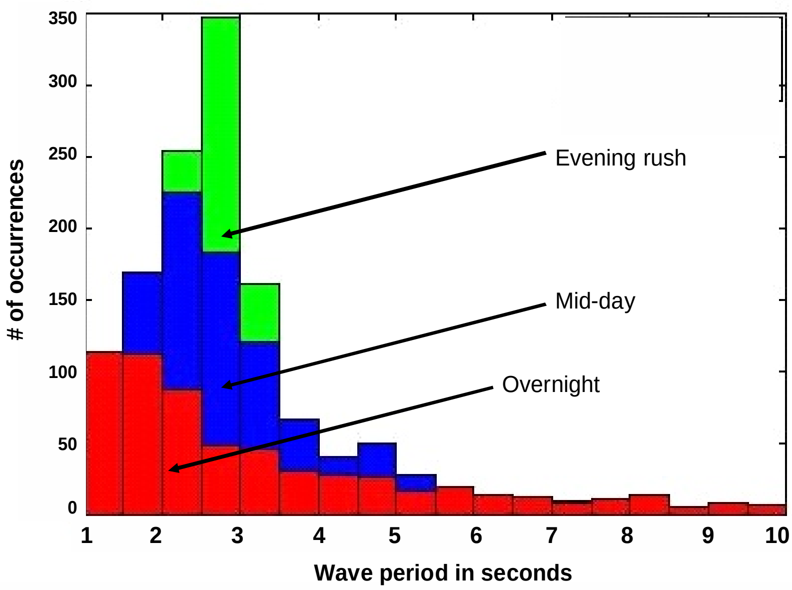

Fig.3: Histogram of wave period

Until this point in the report, discussion of the observed waves has been limited to describing wave height. However, wave period is a critical measure not only of the energy contained in the wake field, but also of the potential influence of the wakes on vessels and shoreline infrastructure. In addition, the performance of partial wave barriers, such as floating breakwaters, is strongly affected by wave period. Observed wave periods ranged from 1 to 10 seconds. Histograms of wave period for different time periods are presented in Fig.3. The peak of the histogram falls in the 1 to 2 second range during a typical overnight hour. During the typical midday hour, the peak moves to the 1.5 to 3.0 second range and the number of occurrences in the 3 to 5 second range increases by nearly 50%. During a typical hour in the evening rush, the peak period again moves up, now to the 2.5 to 3.0 second range. During the evening rush, the number of occurrences of periods greater than 3.0 seconds is very similar to that which was observed during the midday, which is significantly greater than is observed in the calm overnight hours.

2.2. Field Observations, July, 2004

A follow-up field study was conducted in July, 2004 in order to obtain a higher-resolution dataset regarding wake characteristics, and the relationship between time of ferry vessel passage and associated wave characteristics. In order to accomplish this task, an ultrasonic acoustic water level gauge operating at a frequency of 10 Hz was used to measure wave activity in New York Harbor. The gauge was located at the western Hudson River Shoreline just south of the Hoboken North ferry terminal, Fig.1. Wave data was logged on July 20th starting at 5:20 am before any boat activity in the harbor. Times of ferry vessel passage were noted, and measurements were taken throughout the day until 7 pm.

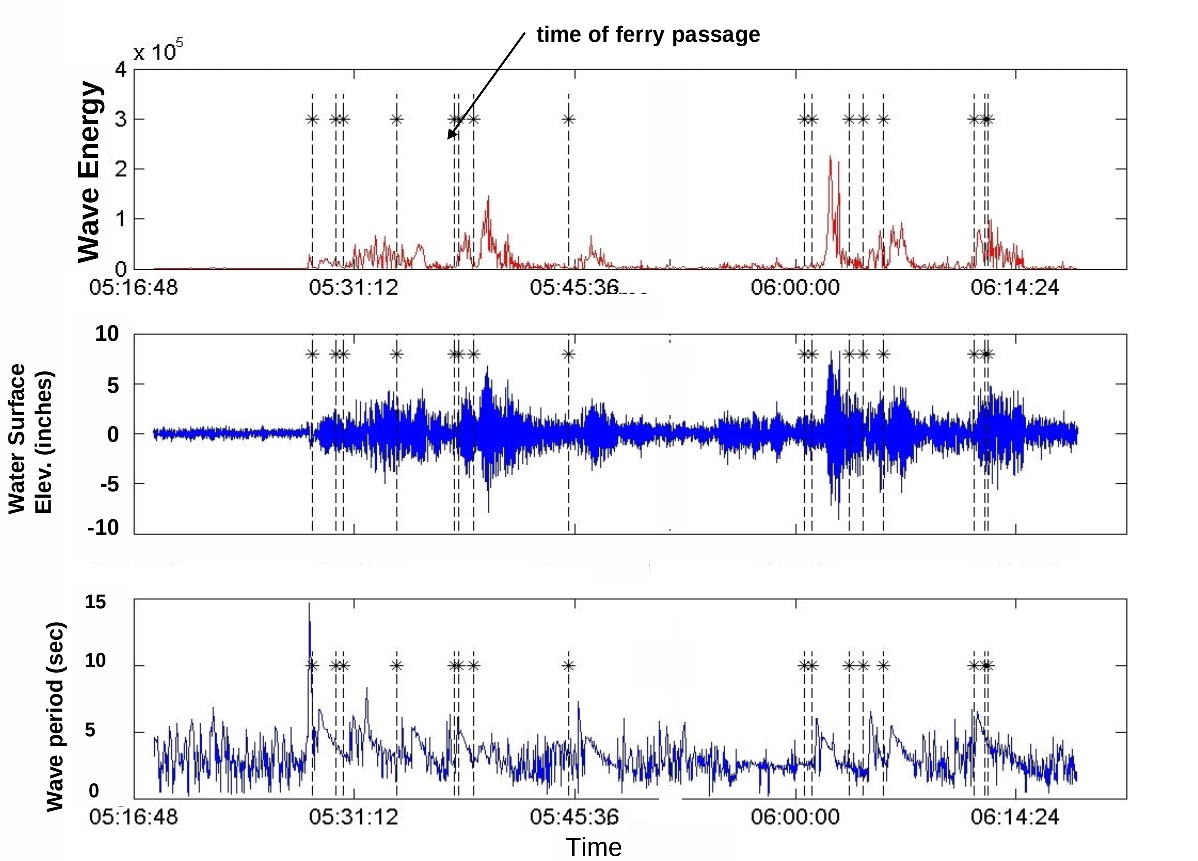

Fig.4: Wake characteristics and times of ferry vessel passage

Fig.4 illustrates the wave energy, water surface elevation (with tide removed) and wave period for the first hour of measurements, at the start of the morning rush hour. Clearly, the times of vessel passage are associated with sudden increases in the measured wave energy, with maximum wave energy levels experienced during time periods when several vessels passed in close proximity to one another. This finding is likely at least in part attributable to the wave summation associated with reflections from the shoreline. The figure does not indicate the type and speed of the ferry in each instance, although these records do exist. A computer modeling effort is underway to examine the wake generation characteristics of each vessel type under the observed speed and water depth conditions. This analysis will help explain the variability in wave height and period observed here.

2.3. Laboratory studies

Tests were conducted in the Davidson Laboratory High-Speed Towing Tank, which is 313 ft (95.5 m) long, 12 ft (3.7 m) wide and 6 ft (1.8 m) deep, and has a top speed of 100 ft/s (30.5 m/s). Four different vessels, whose characteristics are given in Table I, were tested to study their wake characteristics in addition to the standard resistance and seakeeping performance characteristics.

Table I: Model characteristics

Hull	Catamaran	Monohull	Catamaran	Catamaran
Length	71.2 ft (21.7 m)	65 ft (19.8 m)	105 ft (32 m)	90 ft (27.4 m)
Beam	27.5 ft (8.4 m)	14 ft (4.3 m)	28.4 ft (8.7 m)	34 ft (10.4 m)
Draft	3.4 ft (1 m)	3 ft (0.9 m)	3.45 ft (1.1 m)	5 ft (1.5 m)
Model scale	1/12	1/12	1/20	1/16

The first model, that of the 71 ft Catamaran, was tested in October 2000 but NY Waterway decided not to consider it for their fleet. The 65 ft Monohull, “The Sea Otter”, was tested in April 2001 and NY Waterway currently operates 3 of these vessels. The 105 ft catamaran design was tested in July 2001 and NY Waterway is in the process of commissioning a few of these vessels. Finally, the 90 ft Catamaran that was tested in September 2002 will be part of the future NY Waterway fleet.

Each model was free to trim and heave, but fixed in yaw, roll, surge and sway. The vertical motion of the tow-point was measured using a motion transducer attached to the free-to-heave apparatus. Trim of the model keel relative to the horizon was measured using an inclinometer mounted on the connecting platform. Resistance was measured using a drag balance located directly above the pivot box. Two accelerometers were mounted near the bow and CG to record vertical acceleration in wave tests. Wake height measurements were made in calm water tests using two resistance-type wave probes at fixed locations in the tank. The two probes were located in that section of the tank where the model runs at constant speed and at transverse distances of 3 ft and 5 ft (model scale) from the ship centerline. The time history of the wake was recorded as the model passed by. A video camera was located on the carriage and video recordings were made of each run. Still photographs using a camera mounted on the carriage were also taken for most of the runs. Data were acquired at 250 Hz in a 100 ft “data trap”.

The full-scale wake heights measured from each of the model test are presented in Tables II to V. Some of the typical trends that can be observed are: the wake heights increase with the displacement, the newer designs tend to have lesser wake heights, the wake heights are higher at the transition (hump condition) speeds and decrease at higher speeds, wake heights depend on the location of the center of gravity and the running trim. To emphasize the wake height variation with speed, the data from the 71 ft Monohull “Sea Otter” is presented in Fig.5.

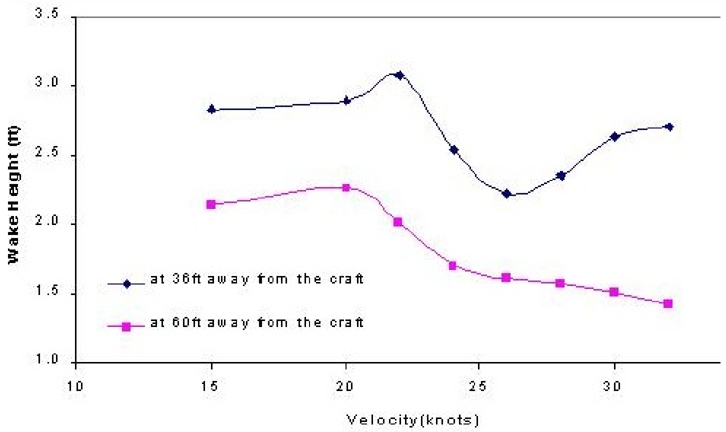

Fig.5: Wake characteristics for the 71 ft. monohull ferry: wake height vs. speed

Table II: Wave heights for 71 ft catamaran (different displacements and LCGs)

Run #	Speed (knots)	Wake Heights (ft) Measured at 36 ft	Wake Heights (ft) Measured at 60 ft
55 LT - 3 ft			
27	15	2.9	2.9
28	20	3	2.8
29	22	2.8	2.8
30	24	2.2	2
31	26	2.2	1.8
55 LT - 5 ft			
33	20	3.2	2.8
34	22	2.8	2.4
35	24	2.4	2.2
36	26	2	1.8
37	28	1.8	1.7
38	30	1.6	1.5
60 LT - 3 ft			
41	15	2.5	2.4
42	20	3	3
43	22	3.2	3
44	24	2.8	2.7
45	26	1.9	1.9
46	28	1.8	1.7
47	30	1.4	1.3
60 LT - 5 ft			
49	15	2.5	2.5
50	20	2.9	2.9
51	22	3.2	2.8
52	24	2.8	2.8
53	26	2.4	2.3
54	28	2	2
55	30	1.8	1.7
60 LT - 7 ft			
59	20	2.7	2.7
60	22	3.2	2.8
61	24	2.8	2.6
62	26	2.4	2.2
65 LT - 3 ft			
64	15	2.8	2.6
66	20	3.6	3.2
67	22	2.8	2.8
68	24	2.6	2.6
69	26	2.2	2.2
65 LT - 5 ft			
71	15	2.8	2.8
72	20	3.6	3.2
73	22	3	2.8
74	24	2.6	2.6
75	26	2.2	2.2
65 LT - 7 ft			
77	20	2.7	2.7
78	22	3.4	2.9
79	24	2.8	2.6
80	26	2.5	2.5
55 LT - 3 ft			
82	20	3	2.8
83	22	2.8	2.5
84	24	2.4	2.1
85	26	2	1.9
50 LT - 5 ft			
88	15	3.2	2.9
89	20	2.8	2.6
90	22	2.5	2.3
91	24	2	1.7
92	26	1.9	1.6
93	28	1.5	1.3
94	30	1.4	1.2

Table III: Wave heights for 65 ft monohull (different displacements and LCGs)

Run # No.	Velocity (kn)	Wake Height(ft) at 36ft	at 60ft
73,990lb. - 39.8 ft			
4	15	2.8	2.1
5	20	2.9	2.3
6	22	3.1	2.0
7	24	2.5	1.7
8	26	2.2	1.6
9	28	2.4	1.6
10	30	2.6	1.5
11	32	2.7	1.4
repeat check			
13	24	2.7	1.6
Tests with LCG variation at 73,990 lb.			
37.8 ft			
15	26	2.4	1.6
38.8 ft			
17	26	2.3	1.6
41.8 ft			
21	26	2.7	1.8
40.8 ft			
19	26	2.7	1.6
23	28	2.7	1.5
24	30	2.7	1.5
25	32	2.7	1.5
49,640 lb. - 39.9 ft			
27	10	0.7	0.2
28	15	1.5	0.7
29	20	2.0	1.6
30	22	1.9	1.3
31	24	1.7	1.1
32	26	1.5	1.2
33	28	1.8	1.0
34	30	1.8	1.0
35	32	1.8	0.8
repeat check			
36	24	1.8	1.2
49,640 lb. - 40.9 ft			
40	26	1.8	1.0
41	28	2.0	1.0
42	30	1.9	0.9
43	32	1.8	0.9
44	40	1.6	0.7
45	42	1.5	0.8

Run # No.	Velocity (kn)	Wake Height(ft) at 36 ft	at 60 ft
62,500 lb. - 39.8 ft			
49	20	2.5	2.0
50	22	2.4	1.6
52	24	2.2	1.3
53	26	2.2	1.2
54	30	2.3	1.2
55	32	2.2	1.1
40.8 ft			
63	30	2.4	1.2
Tests using 2.75" interrupters at 62,500 lb.			
1/16" projection - 39.8 ft LCG			
57	15	1.9	0.8
59	26	1.7	1.3
1/16" projection - 40.8 ft LCG			
61	26	1.9	1.3
62	30	1.9	1.1
1/32" projection - 40.8 ft LCG			
67	30	1.8	0.9
Tests using interrupters at 73,990 lb.			
2.75" long - 1/32" projection - 39.8 ft LCG			
70	26	1.2	1.8
1.4" long - 1/32" projection - 39.8 ft LCG			
72	26	2.3	1.6
73	30	2.3	1.4
1.4" long - 1/32" projection - 40.8 ft LCG			
75	30	2.3	1.3
76	26	2.5	1.6
Tests using Trim Wedges at 73,990 lb. And 39.8 ft			
3.5"X1" - 5 deg. Wedges			
79	26	2.0	1.5
3.5"X1" - 3 deg. Wedges			
82	30	2.4	1.4

3. Results and discussion

The wake heights and periods found in the field measurements agree qualitatively with what was observed during the physical model tests. For this reason, it would be expected that modification of operational parameters such as speed and trim to be more in line with the optimum values predicted by the physical model tests would lessen wakes created by a particular vessel. For vessels currently operating in their most inefficient regimes, the potential reduction in wake energy can be substantial.

Table IV: Wave heights for 105 ft catamaran (different displacements and LCGs)

Run # No.	Vs (kn)	Wake Heights (ft) at 60ft	at 100 ft	Run # No.	Vs (kn)	Wake Height (ft) at 60ft	at 100 ft
195,610 lb - 59.5 ft				***195,610 lb - 59.5 ft***			
9	10	0.6	0.5	49	20	4.0	3.2
10	15	1.5	0.9	50	24	2.5	2.0
11	20	2.2	1.0	51	27	2.2	1.9
12	22	2.6	1.5	52	30	1.9	1.6
13	24	2.6	2.5	55	34	1.6	1.1
15	26	2.5	1.9				
14	28	2.2	1.8	***150,850 lb. - 61.25 ft***			
16	30	1.8	1.6	57	19	3.1	1.3
				58	20	2.3	1.7
195,610 lb - 62.5 ft				59	24	2.0	1.5
19	20	2.9	2.2	60	28	1.7	1.4
21	24	2.7	2.4	61	30	1.5	1.2
22	26	2.4	2.1	62	32	1.4	1.1
23	28	2.0	1.8	64	36	1.2	0.9
24	30	2.0	1.5	66	40	1.1	0.8
25	32	2.0	1.4				
26	34	1.8	1.4	***150,850 lb. - 63.25 ft***			
27	36	1.6	1.1	68	20	2.2	1.7
28	38	1.7	1.1	69	24	2.1	1.5
29	40	1.6	1.0	70	24	2.1	1.5
30	41	1.6	1.0	71	28	1.8	1.3
				72	30	1.6	1.2
**** Chines Widened near the Bow***				73	32	1.5	1.1
195,610 lb - 62.5 ft				75	41	1.3	0.8
32	20	1.6	1.2				
33	24	2.5	1.9	***225,000 lb. - 62.5 ft***			
34	28	1.9	1.8	77	20	2.3	1.1
35	30	1.8	1.6	78	24	2.9	2.2
37	32	1.7	1.4	79	28	1.7	2.0
38	34	1.7	1.2	80	30	2.4	1.7
				81	32	1.9	1.4
195,610 lb - 59.5 ft				82	34	1.8	1.4
40	20	2.2	2.1				
41	24	2.6	1.9	***225,000 lb. - 64 ft***			
44	26	2.0	1.8	84	24	2.9	2.2
45	30	1.9	1.6	85	28	2.3	2.1
46	32	1.8	1.3	86	32	2.0	1.4

The largest amount of wake energy created per unit time occurs during the transition from displacement to planing mode. This was observed in the physical model tests and suggested in the qualitative field study. In many cases (especially the newer hulls), higher speeds result in lower wave energy. Again, with the guidance provided by physical model tests of hulls, these optimum speeds must be known and adhered to by vessel operators whenever possible to minimize wake. As little time as possible should be spent in the transition zone. Again, for vessels that are currently being operated for long periods of time at the very high end of displacement (very low end of planing) substantial decreases in wake energy will be possible by this optimization.

Table V: Different loads and trims

Run #	Vel (fps)	Wake Height (ft) (at 80 ft)	Run #	Vel (fps)	Wake Height (ft) (at 80 ft)
100 LT - Level Trim			***110 LT - Level Trim***		
1	0.00	0.0	19	0.00	0.0
2	4.02	--	20	8.37	3.2
3	6.23	2.8	21	10.52	--
4	8.37	3.1	22	11.38	--
5	10.52	--	23	12.69	1.1
6	11.36	2.1	24	13.54	1.2
7	12.68	1.3	25	14.82	1.2
8	13.51	1.2	26	15.69	1.2
9	14.82	1.1	27	16.99	0.9
10	15.67	1.1			
11	17.00	0.9	***90 LT - Level Trim***		
12	12.67	1.2	28	0.00	0.0
			29	8.38	2.9
100 LT - 2 deg Trim			30	10.54	2.5
14	0.00	0.0	31	11.39	--
15	8.37	3.5	32	12.70	1.2
16	10.52	--	37	13.55	1.2
17	12.67	1.1	34	14.86	1.2
18	14.84	0.8	35	15.71	1.1
			36	17.01	0.9

The qualitative field study also strongly suggested that sharp turns in the transition phase could result in the focusing of wave energy, especially to the inside of turns. The qualitative evidence is strong enough on its own in this specific area to warrant the minimization of any sharp turns during the transition phase if any wake-sensitive areas are located on the inside of the turn.

Wave shoaling is taking place during at least some stages of the tide in the shallowest areas of the shorelines, some of which contain marinas. Deepening (dredging) these specific areas has the potential to reduce wave heights by 30% in some of the shallowest regions. Deepening by itself will not completely mitigate any wake problem in this harbor, but should be considered part of the total approach.

In places where reflective shorelines (vertical or near vertical walls) border water deeper than 2 feet MLLW, most of the incoming wave energy is simply reflected back into the Harbor. Efforts should be taken wherever possible to limit reflective shorelines. Again, simply replacing reflective shorelines with dissipative shorelines will not completely mitigate the wake problem, but will prevent exacerbating the situation and is an important part of any total approach.

Our study indicated that ferry wakes are responsible for a good portion of the wave energy in the ferry operating region, with maximum contribution during the weekday rush hours. Our analysis indicates that the wakes produced by high-speed ferry vessels differ in many important respects from wakes produced by more slowly moving vessels. The most damaging wakes, in terms of height, occur at low speeds, particularly during the transition from low-speed displacement mode to planing mode, and during certain turning maneuvers. The length of the ferry wakes is in general significantly longer than the length of wakes associated with even larger, slow-moving (displacement-mode) vessels operating in the Harbor. It is this large wavelength that allows wake energy to pass through the various wave protection devices in use at marinas along the Hudson River shoreline, including floating barriers and partial-depth wave screens.

Wake characteristics vary not only as a function of the vessel's speed, trim, and direction of travel, but also as a function of hull characteristics. Hull designs that more easily achieve high-speed planing are far more energy efficient and generate far lower wake energy than less efficient hull designs. Clearly, hull designs that minimize wake production are desirable from both an adverse impacts standpoint and an operational standpoint.

These findings have led to the following recommendations:

1) Ferry Operators

Assign the most efficient hulls to the most wake-sensitive areas.

Determine the most efficient operating range (speed and trim) for each vessel class and operate each vessel within this range as much as is practicable, with as little time as possible spent in the transition phase between the displacement and planing modes.

Ferry routing should be carefully evaluated, and modified to ensure minimal time spent in the transition phase while adjacent to or pointing toward wake-sensitive shoreline areas, and to avoid turning with a wake-sensitive area inside the turn. In general, a ferry should proceed from the dock to the center of the navigation channel at a speed well below transition (that is, well within displacement mode), then make its turn to proceed in an along-channel direction, rapidly accelerate to high-speed planing mode until adjacent to the next stop, decelerate to a speed well within displacement mode, then turn toward the dock.

We recommend against blanket speed restrictions, as such restrictions will very likely have the unintended effect of increasing the height of wakes produced by ferry vessels that are designed for efficient operation at high speeds.

2) Marina Operators

Should be permitted to construct wave protection systems that can protect the dock areas from waves exceeding 20 inches in height and 4.25 seconds in period. An example of such a system is a full-depth timber wave screen.

Avoid reflective side banks to the degree possible.

Optimize entrance channel design to avoid direct exposure to wakes produced by passing vessels.

3) Regulatory Authorities

Examine permitting requirements that prohibit the installation of effective wave protection systems along marina and other wake-sensitive shoreline areas.

4) General Public

As the revitalization of waterways and shorelines continues, and as more people take to the water in vessels of all sizes and types, there will be an increasing need to educate the boating public about the rules of the road when operating a vessel in a commercial harbor. The production and widespread dissemination of Harbor maps that clearly delineate active navigation channels, loading and unloading areas, and ferry routes, would be an important first step in this regard, as would public outreach activities that would include the participation of commercial vessel operators in the Harbor.